Article

Influence of Isokinetic Muscle Strength Training Combined With Early Functional Exercise on Joint Function After Knee Cruciate Ligament Reconstruction

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AIM: The purpose of this study was to evaluate and analyze the influence of isokinetic muscle strength training combined with early functional exercise on joint function after knee cruciate ligament reconstruction.
METHODS: A total of 294 patients undergoing knee cruciate ligament reconstruction from January 2023 to June 2025 were retrospectively selected. Based on different exercise methods, 155 patients who received early functional exercise for 24 weeks were included in a control group (CG), and the other 139 patients receiving isokinetic muscle strength training (starting from the 4th week after surgery) combined with early functional exercise were enrolled as an experimental group (EG). After propensity score matching (PSM), 252 patients were retained for analysis, including 126 cases in the EG and 126 cases in the CG. The primary clinical outcomes encompassed International Knee Documentation Committee Subjective Knee Form (IKDCSKF) and Knee Injury and Osteoarthritis Outcome Score (KOOS) before training (T0) and at 8 weeks (T1), 12 weeks (T2) and 24 weeks (T3) after surgery, and the secondary outcomes included joint range of motion (ROM) and isokinetic muscle strength test results involving extensor peak torque (EPT), flexor peak torque (FPT) and hamstrings/quadriceps (H/Q).
RESULTS: Repeated measures analysis of variance (ANOVA) revealed significant group × time interaction effects for both IKDCSKF and KOOS scores (both $p < 0.001$), indicating different improvement trajectories between the two groups. Significant time effects and group effects were also observed for both outcomes (both $p < 0.001$). Post hoc analysis with Bonferroni correction demonstrated that the EG group had significantly higher IKDCSKF and KOOS scores than the CG group at T1, T2, and T3 ($p < 0.05$ or $p < 0.001$), with more pronounced differences observed at T2 and T3 (all $p < 0.001$). At T3, EG had higher ROM, EPT, FPT and H/Q than CG ($p < 0.001$, $p < 0.001$, $p < 0.001$, $p = 0.001$). No significant difference was found in the proportion of patients with normal H/Q between the two groups ($\chi^2 = 0.06$, $p = 0.798$). The β (95% CI) for EG on IKDCSKF score was 4.35 (2.82~5.87), and the β (95% CI) on KOOS score was 5.22 (3.91~6.53).
CONCLUSIONS: Isokinetic muscle strength training combined with early functional exercise was associated with greater improvement in joint function and knee flexor and extensor muscle strength in patients undergoing knee cruciate ligament reconstruction. In addition, the intervention protocol may be independently associated with the patient's joint function.

Keywords: isokinetic muscle strength training; functional exercise; knee cruciate ligament reconstruction; joint function; early rehabilitation

Introduction

The anterior cruciate ligament (ACL) is an important stable structure located in the knee joint, and it originates from the anterior depression of the medial intercondylar spine of the tibial plateau and attaches to the anterior horn of the lateral meniscus [1,2]. Epidemiological data indicate that ACL injury is one of the most common conditions in sports medicine, with a higher incidence in males than in females across most age groups [3,4]. Knee cruciate ligament reconstruction is currently the primary surgical treatment method in clinical practice [5]. Patients undergoing ACL reconstruction are prone to a series of postoperative complications, including joint involvement (effusion, pain, mechanoreceptor damage), activity limitation, impaired proprioception and decreased muscle strength. Among these complications, decreased muscle strength is the most dominant factor limiting knee functional recovery

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and severely compromising dynamic knee stability [6,7]. It is currently widely accepted that the causes of decreased muscle strength after ACL reconstruction are disuse muscle atrophy and arthrogenic muscle inhibition [8]. Insufficient lower limb muscle strength can lead to abnormal gait, resulting in altered lower limb alignment and load distribution, persistent dynamic knee instability and increased risks of knee osteoarthritis and secondary injuries [9,10].

The concept of isokinetic motion was first proposed by Hislop and Perrine in the late 1960s. Isokinetic training can be tailored to different phases of rehabilitation, progressing from multi-point isometric motion in the early phase to moderate-to-high-speed concentric motion in the mid-phase, and finally to low-speed eccentric motion in the late phase for muscle tensile resistance and re-injury prevention [11]. Both isokinetic concentric and eccentric training modalities can increase muscle contraction forces, with eccentric training additionally benefiting neuromuscular control recovery due to its low energy consumption and high strength characteristics [12,13]. This study aimed to investigate the effects of combined isokinetic muscle strength training and early functional exercise on joint function recovery after knee cruciate ligament reconstruction, and to analyze whether this combined training regimen can provide a theoretical basis for individualized postoperative rehabilitation regimens by improving periarticular muscle strength and neuromuscular coordination.

Methods

Study Population

Patients undergoing knee cruciate ligament reconstruction were retrospectively selected between January 2023 and June 2025 and received either 24 weeks of early functional exercise or isokinetic muscle strength training (beginning in the 4th week after surgery) combined with early functional exercise. Inclusion criteria were as follows: (1) patients receiving knee cruciate ligament reconstruction at the hospital due to pure anterior cruciate ligament injury, with surgeries performed by the same team of surgeons; (2) patients aged 18–50 years; (3) patients with first-time injury, with time interval between injury and surgery <4 weeks, and involving unilateral limb injury; (4) patients without severe complications such as infection and lower limb thrombosis; (5) patients with complete clinical data and follow-up results.

Exclusion criteria were as follows: (1) patients with concurrent injuries to the meniscus, posterior cruciate ligament or medial and lateral collateral ligaments; (2) patients with concurrent lower limb fracture, vascular injury or nerve injury; (3) patients with a previous history of surgery around the knee joint; (4) patients receiving other rehabilitation interventions or oral nutrition-related muscle agents in addition to the experimental rehabilitation procedures; (5) pregnant or lactating women.

Rehabilitation Methods

Control group (CG) patients received early functional exercise. Phase 1 (0–3 weeks after surgery) included ankle pump exercise, isometric contraction of the quadriceps femoris, isometric contraction of the hamstrings, straight-leg raising in prone, supine and lateral positions, resistance training for ankle dorsiflexion and plantarflexion, as well as knee extension training. Phase 2 (4–8 weeks after surgery) involved ankle pump exercise, resistance-free/resistance straight-leg raising in prone, supine and lateral positions, center of gravity transfer training (side-to-side and front-to-back), passive knee flexion training, knee extension training, active knee flexion training (knee flexion range of motion >120° by the 6th week, aiming for full range as far as possible by the 8th week) and patellar push training. In phase 3 (9–24 weeks after surgery), seated knee-hug training, heel-lifting training, single-leg balance training, wall-supported static squat, static glute bridge training, straight-leg plate support training, standing resistance training for hip flexion, extension, adduction and abduction, seated hamstring training, quadriceps stretch training and standing triceps surae stretch training were completed.

Experimental group (EG) patients received isokinetic strength training in addition to the early functional exercise protocol. The early functional exercise regimen was identical to that administered in the CG. With regard to isokinetic muscle strength training (starting from the 4th week after surgery) combined with early functional exercise, the HUMAC NORM isokinetic machine from CSMI Company in the United States was used to assess muscle strength. The therapist first provided a brief explanation and demonstration to ensure the patients fully understood the training procedure, and then guided the patients to sit on the test chair, fixed the trunk and the affected thigh with the chair's elastic straps, and adjusted the position of the test chair relative to the equipment so that the knee's axis of motion aligned with the power arm's axis. The resistance pad at the end of the power arm was secured 3 cm above the superior border of the ankle joint. Short-arc isokinetic concentric training for the quadriceps femoris (0–30°, angular velocity of 60°/s, 10–15 repetitions per set for 3 sets, 3 times per week) and isokinetic concentric strength training for the hamstrings (0–100°, angular velocity of 60, 90 and 120°/s, 10–15 repetitions per set for 3 sets, 3 times per week) were implemented at 4–8 weeks after surgery. Short-arc isokinetic concentric/eccentric training for the quadriceps femoris (0–30°, angular velocity of 30°/s, 20 repetitions per set for 3 sets, 3 times per week), isokinetic concentric strength training for the hamstrings (0–100°, angular velocity of 60, 90 and 120°/s, 10–15 repetitions per set for 3 sets, 3 times per week) and isokinetic concentric strength training for the quadriceps femoris and hamstrings (30–100°, angular velocity of 90, 120, 180, 210, 210, 180, 120 and 90°/s, 10–15 repetitions per set for 8 sets, 3 times per week) were conducted at 9–12 weeks after surgery. Short-arc isokinetic concentric/eccentric training for the quadriceps femoris (0–

30°, angular velocity of 60°/s, 20 repetitions per set for 3 sets, 3 times per week) and isokinetic concentric/eccentric strength training for the quadriceps femoris and hamstrings (0–100°, angular velocity of 60, 90, 120, 150, 150, 120, 90 and 60°/s, 10–15 repetitions per set for 8 sets, 3 times per week) were carried out at 13–24 weeks after surgery.

Indicator Collection

Primary clinical outcomes were the International Knee Documentation Committee Subjective Knee Form (IKDCSKF) [14] and Knee Injury and Osteoarthritis Outcome Score (KOOS) [15] before training (T0) and at 8 weeks after surgery (T1), 12 weeks after surgery (T2) and 24 weeks after surgery (T3). T0 was defined as the time point before the start of isokinetic training for the EG corresponding to the end of the 4th week after surgery. This time point was used as the baseline for outcome comparisons between the two groups. The IKDCSKF is a patient-reported outcome measure used to assess overall knee function. The questionnaire was divided into 3 categories: symptoms, exercise volume, and knee function. The total score is calculated by summing the scores of all items and then converting the results to a scale ranging from 0 to 100, with higher IKDCSKF scores indicating better knee function. KOOS has five separately scored subscales, comprising pain (9 items), symptoms (7 items), activities of daily living (17 items), sports and leisure (5 items) and knee-related quality of life (4 items). Each item is scored on a scale of 0–4 points. The scores of each subscale are calculated separately and converted to a range of 0–100 points, with higher scores representing better knee function.

Secondary outcomes included joint range of motion (ROM) and isokinetic muscle strength test results at T0 and T3. The test indicators encompassed extensor peak torque (EPT), flexor peak torque (FPT) and hamstrings/quadriceps (H/Q). ROM was measured using a specialized goniometer. The fulcrum of the goniometer was placed at the lateral femoral epicondyle, with the stationary arm aligned parallel to the femoral shaft and the moving arm aligned with the fibular shaft toward the lateral malleolus. Patients were instructed to perform three complete cycles of knee extension and flexion. The maximum knee flexion and extension angles were recorded, and the mean value of the three measurements was calculated for analysis. Isokinetic muscle strength test results were obtained using the HUMAC NORM isokinetic muscle strength training and assessment system from CSMI Company in the United States. On the day of the test, patients were instructed to refrain from any physical activity and were required to perform low-speed bicycle training without resistance during a 10-minute warm-up period. The computer was used to select a knee flexion-extension concentric strength test at an angular velocity of 60°/s, with five repetitions recorded for evaluation. Lower limb weight correction was performed prior to the test to eliminate the effects of gravity during lower limb movement, and the knee ROM was set to 0–90°. During the test, patients were encouraged to exert maximum effort within their pain tolerance to ensure the accuracy and reliability of the test results. Patient performance and equipment feedback were closely monitored to ensure that the test proceeded normally.

Data Management and Quality Assurance

Data collection and entry were completed independently by the two researchers in accordance with the predefined standardized protocol. Outcome assessors and data analysts were blinded to the study. Patient personal information was strictly confidential, and all data were anonymized and used solely for research analysis.

Statistical Analysis

The statistical analyses were performed using SPSS 27.0 software (SPSS Inc., Chicago, IL, USA). Shapiro-Wilk test was used to assess the normality of data distribution. Normally distributed continuous variables were expressed as mean ± SD, whereas non-normally distributed continuous variables were presented as [M (Q_1, Q_3)]. Categorical data were presented as n (%) and compared using Chi-square test or Fisher's exact test. Repeated measures analysis of variance (ANOVA) was conducted for the primary outcomes (IKDCSKF and KOOS scores). For the group × time interaction effect, post hoc pairwise comparisons were performed to examine between-group differences at each time point (T1, T2, T3). Between-group comparisons at each time point were performed using independent-samples *t*-tests. To account for multiple comparisons among the three post hoc between-group comparisons (T1, T2, and T3), Bonferroni correction was applied separately for each outcome across the three post hoc between-group comparisons (T1, T2, T3), yielding an adjusted significance threshold of $\alpha = 0.05/3 \approx 0.0167$ per outcome. The linear regression multi-model strategy was employed to assess whether isokinetic muscle strength training combined with early functional exercises was independently associated with the IKDCSKF and KOOS scores. In the linear regression models, the dependent variables were the IKDCSKF and KOOS scores at T3. Baseline (T0) scores were not included as covariates because the two groups were well balanced at baseline after propensity score matching (PSM) (IKDCSKF: 50.23 ± 4.30 vs. 49.64 ± 3.94; KOOS: 54.51 ± 3.96 vs. 54.33 ± 3.56). Moreover, the primary analysis using repeated measures ANOVA already accounted for the longitudinal structure of the data, and the regression models were intended to provide complementary estimates of the association between the intervention and the outcomes at the final follow-up after adjusting for potential confounders. The significance level was set at a two-sided $\alpha = 0.05$.

Results

Demographic Characteristics

This study collected 294 patients undergoing knee cruciate ligament reconstruction. According to different ex-

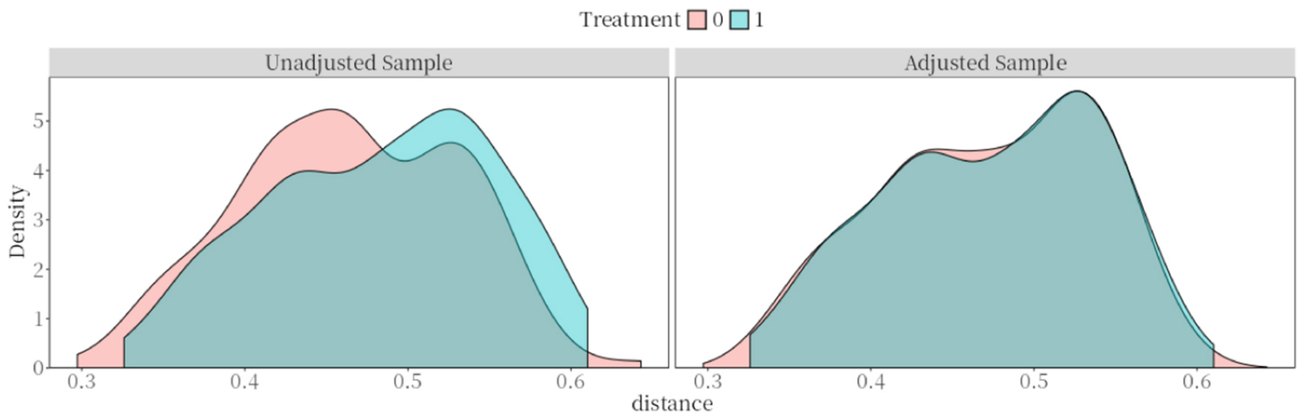

Fig. 1. Probability density analysis before and after propensity score matching (PSM).

ercise regimens, 155 patients who underwent 24 weeks of early functional exercise were classified as the control group (CG), and 139 patients who received isokinetic muscle strength training (beginning in the 4th week after surgery) combined with early functional exercise were collected as the experimental group (EG). To reduce potential selection bias inherent in the retrospective design and to balance baseline covariates between the two groups, propensity score matching (PSM) was applied. Control variables included age, body mass index (BMI), gender, ligament type, meniscus treatment, cartilage injury and surgical side. Nearest-neighbor matching was performed using a caliper value of 0.1 and a 1:1 matching ratio. Ultimately, a total of 252 patients were enrolled in the study, comprising 126 cases in the EG and 126 cases in the CG.

Shapiro-Wilk test results indicated that age ($p = 0.010$) was not normally distributed, while the other continuous variables showed a normal distribution. As detailed in Table 1, the baseline characteristics of the two groups of patients were well balanced after PSM. The probability density analysis before and after PSM was displayed in Fig. 1.

Comparison of Primary Outcomes Between the Two Groups

A two-way repeated-measures analysis of variance (ANOVA) was performed to compare changes in IKDCSKF and KOOS scores between the two groups over time. The results of the repeated-measures ANOVA and post hoc comparisons are summarized in Table 2, and the longitudinal changes in IKDCSKF and KOOS scores are presented in Fig. 2.

For the IKDCSKF score, a significant group × time interaction effect was observed between the two groups ($F = 14.80$, $p < 0.001$), indicating that the changes in IKDCSKF scores over time differed between the CG and EG groups. Significant main effects of time ($F = 1303.05$, $p < 0.001$) and group ($F = 55.19$, $p < 0.001$) were also observed. Post hoc multiple comparisons showed no significant difference in IKDCSKF scores between the two groups at baseline (T0, $p > 0.05$). However, the EG group exhibited significantly higher IKDCSKF scores than the CG group at T1 ($p = 0.031$), T2 ($p < 0.001$), and T3 ($p < 0.001$).

For the KOOS score, significant group × time interaction ($F = 21.73$, $p < 0.001$), time ($F = 1471.02$, $p < 0.001$), and group ($F = 127.51$, $p < 0.001$) effects were observed. Post hoc multiple comparisons indicated that there was no significant difference in KOOS scores between the two groups at baseline (T0, $p > 0.05$), whereas the EG group had significantly higher KOOS scores than the CG group at T1, T2, and T3 (all $p < 0.001$).

Comparison of Secondary Outcomes Between the Two Groups

According to the Shapiro-Wilk test, the ROM, EPT, FPT and H/Q at T0 and T3 were normally distributed (all $p > 0.05$). As shown in Table 3, the ROM, EPT, FPT and H/Q in the EG were higher than those in the CG at T3 ($p < 0.001$, $p < 0.001$, $p < 0.001$, $p = 0.001$). The normal H/Q range was approximately 0.5–0.6. The proportion of subjects with normal H/Q before and after isokinetic muscle strength training based on this range (0.5–0.6) was statistically compared, and the results were recorded and summarized in a table. At T3, the mean H/Q ratio was significantly higher in the EG than in the CG (0.58 ± 0.10 vs. 0.54 ± 0.09, $p = 0.001$). However, no obvious differences were observed in the proportion of subjects with normal H/Q between the two groups ($\chi^2 = 0.06$, $p = 0.798$).

Linear Regression Multi-Model Strategy

The linear regression multi-model strategy was used to analyze whether isokinetic muscle strength training combined with early functional exercise was independently associated with the IKDCSKF and KOOS scores at T3 (the final follow-up), involving Model 1 (crude), Model 2 (adjusted for gender, age, and BMI) and Model 3 (adjusted for gender, ligament type, meniscus treatment, cartilage injury, surgical side, age and BMI). Baseline scores were not included as covariates because the two groups were well balanced after PSM (Table 1). Table 4 summarizes these results. After adjustment for the three aforementioned models, the com-

Table 1. Demographic characteristics between the two groups before and after PSM.

Variables	Before PSM						After PSM					
	Total (n = 294)	CG (n = 155)	EG (n = 139)	Statistic	*p*	SMD	Total (n = 252)	CG (n = 126)	EG (n = 126)	Statistic	*p*	SMD
BMI, Mean ± SD	24.95 ± 3.11	25.17 ± 3.21	24.72 ± 2.99	$t = 1.23$	0.216	–0.150	25.08 ± 2.94	25.13 ± 3.05	25.03 ± 2.83	$t = 0.26$	0.790	–0.035
Age, M (Q_1, Q_3)	33.00 (28.00, 39.00)	33.00 (28.00, 39.00)	33.00 (29.00, 39.00)	Z = –0.02	0.984	0.014	33.00 (29.00, 39.00)	34.00 (28.25, 39.00)	33.00 (29.00, 38.75)	Z = –0.23	0.815	–0.016
Gender, n (%)				$\chi^2 = 0.73$	0.393					$\chi^2 = 0.26$	0.604	
Female	109 (37.07)	61 (39.35)	48 (34.53)			–0.101	96 (38.10)	50 (39.68)	46 (36.51)			–0.066
Male	185 (62.93)	94 (60.65)	91 (65.47)			0.101	156 (61.90)	76 (60.32)	80 (63.49)			0.066
Ligament type, n (%)				$\chi^2 = 0.92$	0.336					$\chi^2 = 0.35$	0.554	
Artificial ligament	33 (11.22)	20 (12.90)	13 (9.35)			–0.122	29 (11.51)	16 (12.70)	13 (10.32)			–0.078
Autologous ligament	261 (88.78)	135 (87.10)	126 (90.65)			0.122	223 (88.49)	110 (87.30)	113 (89.68)			0.078
Meniscus treatment, n (%)				$\chi^2 = 0.40$	0.525					$\chi^2 = 0.06$	0.798	
No	172 (58.50)	88 (56.77)	84 (60.43)			0.075	148 (58.73)	73 (57.94)	75 (59.52)			0.032
Suture	122 (41.50)	67 (43.23)	55 (39.57)			–0.075	104 (41.27)	53 (42.06)	51 (40.48)			–0.032
Cartilage injury, n (%)				$\chi^2 = 0.08$	0.771					$\chi^2 = 0.08$	0.776	
No	278 (94.56)	146 (94.19)	132 (94.96)			0.035	239 (94.84)	120 (95.24)	119 (94.44)			–0.035
Yes	16 (5.44)	9 (5.81)	7 (5.04)			–0.035	13 (5.16)	6 (4.76)	7 (5.56)			0.035
Surgical side, n (%)				$\chi^2 = 2.33$	0.127					$\chi^2 = 0.29$	0.588	
Left side	102 (34.69)	60 (38.71)	42 (30.22)			–0.185	80 (31.75)	38 (30.16)	42 (33.33)			0.067
Right side	192 (65.31)	95 (61.29)	97 (69.78)			0.185	172 (68.25)	88 (69.84)	84 (66.67)			–0.067

t: *t*-test, Z: Mann-Whitney test, χ^2: Chi-square test. PSM, propensity score matching; CG, control group; EG, experimental group; BMI, body mass index.

Table 2. Comparison of IKDCSKF and KOOS Scores between the two groups (points).

Variables	Time point	CG (n = 126)	EG (n = 126)	Group × time	Time	Group	Post hoc multiple comparisons (time)	Post hoc multiple comparisons (Groups)
IKDCSKF score	T0	50.23 ± 4.30	49.64 ± 3.94	$F = 14.80$, $p < 0.001$	$F = 1303.05$, $p < 0.001$	$F = 55.19$, $p < 0.001$	T0 - T1: $p < 0.001$ T0 - T2: $p < 0.001$ T0 - T3: $p < 0.001$	T1: $p = 0.031$; T2: $p < 0.001$; T3: $p < 0.001$
	T1	57.93 ± 4.84	59.24 ± 4.77					
	T2	64.84 ± 5.54	69.52 ± 5.64					
	T3	75.51 ± 6.04	79.89 ± 6.26					
KOOS score	T0	54.51 ± 3.96	54.33 ± 3.56	$F = 21.73$, $p < 0.001$	$F = 1471.02$, $p < 0.001$	$F = 127.51$, $p < 0.001$	T0 - T1: $p < 0.001$ T0 - T2: $p < 0.001$ T0 - T3: $p < 0.001$	T1: $p < 0.001$; T2: $p < 0.001$; T3: $p < 0.001$
	T1	61.75 ± 4.52	64.20 ± 4.35					
	T2	68.25 ± 5.09	74.13 ± 5.62					
	T3	78.65 ± 5.51	83.92 ± 5.00					

p-values for between-group comparisons at each time point were derived from independent-samples *t*-tests with Bonferroni correction for three post hoc comparisons (T1, T2, T3; corrected $\alpha \approx 0.0167$). IKDCSKF, International Knee Documentation Committee Subjective Knee Form; KOOS, Knee Injury and Osteoarthritis Outcome Score.

Table 3. Comparison of secondary outcomes between the two groups.

Variables	Time point	CG (n = 126)	EG (n = 126)	Statistic	p
ROM	T0	85.65 ± 5.08	85.47 ± 4.74	t = 0.29	0.768
	T3	108.66 ± 7.16	113.26 ± 6.34	t = –5.40	<0.001
EPT	T0	51.83 ± 5.06	51.74 ± 4.95	t = 0.15	0.880
	T3	71.94 ± 6.29	77.35 ± 7.03	t = –6.44	<0.001
FPT	T0	28.12 ± 4.09	27.83 ± 4.21	t = 0.56	0.575
	T3	38.58 ± 5.61	44.21 ± 6.45	t = –7.40	<0.001
H/Q	T0	0.55 ± 0.10	0.54 ± 0.10	t = 0.794	0.428
	T3	0.54 ± 0.09	0.58 ± 0.10	t = –3.34	0.001
H/Q	Normal	51 (40.48)	53 (42.06)	χ^2 = 0.06	0.798
	Abnormal	75 (59.52)	73 (57.94)		

t: t-test, χ^2: Chi-square test. ROM, range of motion; EPT, extensor peak torque; FPT, flexor peak torque; H/Q, hamstrings/quadriceps.

bined intervention had a β (95% CI) of 4.35 (2.82~5.87) for the IKDCSKF score and a β (95% CI) of 5.22 (3.91~6.53) for the KOOS score. These results reveal that the combined intervention regimen was significantly associated with improved knee function after controlling for potential confounding factors.

Discussion

This study suggested that isokinetic muscle strength training combined with early functional exercise was associated with greater improvement in joint function in patients after knee cruciate ligament reconstruction. From the aspects of primary outcome indicators, the scores of IKDCSKF and KOOS were significantly higher in the EG than those in the CG at 8, 12 and 24 weeks after surgery. Additionally, the above scores in both groups showed gradually increasing trends over time, and the differences were statistically significant between groups, indicating that this combined intervention regimen was associated with knee function recovery. Regarding secondary outcomes, EG showed higher ROM, EPT, FPT and H/Q compared to CG at 24 weeks after surgery. Furthermore, isokinetic muscle strength training combined with early functional training was shown to be independently associated with higher IKDCSKF and KOOS scores at T3, suggesting that this intervention regimen may offer stable and reliable effectiveness in knee functional outcomes.

Improvements in the IKDCSKF and KOOS scores reflected the cumulative benefit of increased muscle strength and improved range of motion. The significant increase in EPT and FPT in EG patients indicated that isokinetic training effectively increased the maximum torque generation capacity of the quadriceps and hamstring muscles. This finding has important clinical implications, as quadriceps femoris weakness after ACL reconstruction is a major contributor to functional deficits and persistent knee dynamic instability [16,17,18]. Compared with early functional exercise alone, the concentric and centrifugal overload loads provided by the isokinetic force measurement system, which can be dynamically adjusted according to the actual force exerted by the patient at each joint Angle, may have stimulated greater muscle adaptation [19,20]. However, despite higher absolute EPT and FPT, the interpretation of H/Q ratio yielded divergent results depending on the analytical approach. When analyzed as a continuous variable, the mean H/Q ratio was significantly higher in the EG than in the CG at T3 (0.58 vs. 0.54, p = 0.001). However, when categorized based on the clinically normal range (0.5–0.6), the proportion of patients with a normal H/Q ratio did not differ significantly between the two groups (42.06% vs. 40.48%, p = 0.798). This discrepancy suggests that although isokinetic training shifted the distribution of H/Q ratios upward, the magnitude of this improvement was insufficient to shift a substantial number of patients from the abnormal to the normal range. Both groups exhibited mean H/Q values within the normal range at T3, indicating that early functional exercise alone was sufficient to restore muscle balance to a clinically acceptable level in many patients. The additional benefit of isokinetic training, while statistically detectable at the group level, may have been observed among patients whose H/Q ratios were already close to the normal threshold, thereby increasing overall group mean but not significantly altering the proportion of patients classified as within the normal range. This finding highlights the distinction between statistical significance and clinical relevance, suggesting that the added value of isokinetic training for muscle balance may be more pronounced in patients with more severe baseline deficits.

Maestroni et al. [21] hold that measuring quadriceps strength through an isokinetic muscle strength test in patients with ACL reconstruction can help to determine their readiness to return to sports and reduce the risk of secondary ACL injury. Furthermore, a linear regression multi-model strategy was employed to explore whether isokinetic muscle strength training combined with early functional exercise would have been independently associated with the IKDCSKF and KOOS scores. After adjusting for gender, ligament type, meniscus treatment, cartilage injury, surgical side, age and BMI, isokinetic muscle strength training combined with early functional exercise was shown

Table 4. Linear regression multi-model strategy.

Variables	Model 1		Model 2		Model 3	
	β (95%CI)	*p*	β (95%CI)	*p*	β (95%CI)	*p*
IKDCSKF score						
CG	0.00 (Reference)		0.00 (Reference)		0.00 (Reference)	
EG	4.38 (2.86~5.90)	<0.001	4.34 (2.83~5.85)	<0.001	4.35 (2.82~5.87)	<0.001
KOOS score						
CG	0.00 (Reference)		0.00 (Reference)		0.00 (Reference)	
EG	5.27 (3.97~6.57)	<0.001	5.28 (3.97~6.58)	<0.001	5.22 (3.91~6.53)	<0.001

Dependent variable: IKDCSKF score at T3 (upper panel) and KOOS score at T3 (lower panel). Model 1: crude model. Model 2: adjusted for gender, age, and BMI. Model 3: adjusted for gender, ligament type, meniscus treatment, cartilage injury, surgical side, age, and BMI.

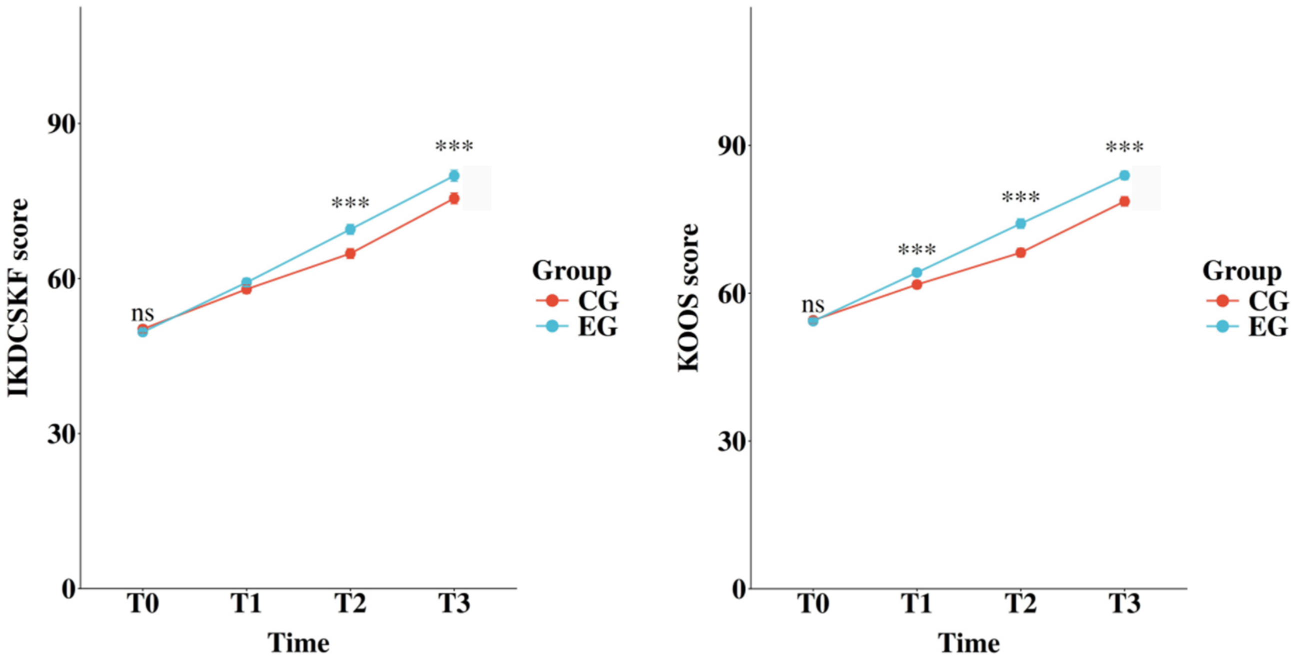

Fig. 2. Changes of IKDCSKF and KOOS scores between the two groups. Symbols indicate significant differences between the control group (CG) and experimental group (EG) at the corresponding time points. *** $p < 0.001$. IKDCSKF, International Knee Documentation Committee Subjective Knee Form; KOOS, Knee Injury and Osteoarthritis Outcome Score; ns, not significant.

to be independently associated with higher IKDCSKF and KOOS scores (both $p < 0.001$). In summary, the findings of this study suggest that both early functional exercise and isokinetic muscle strength training can improve knee function and enhance knee flexor and extensor muscle strength.

This study has certain limitations: (1) As a retrospective analysis, PSM was employed to control for potential selection bias and information bias, but the influence of confounding factors on the results cannot be eliminated. (2) The sample size is relatively limited, and the data are from a single center, possibly limiting the generalizability of the findings. (3) Knee flexor and extensor muscle strength was greatly influenced by gender and age. Given the wide age range of the study samples, long-term, large-sample, and more systematic clinical studies should be considered to guide further rehabilitation treatment. (4) The study period was relatively short, yielding preliminary training results that cannot fully assess the potential benefits of long-term training.

Conclusions

In this retrospective, propensity-matched study, isokinetic muscle strength training combined with early functional exercise was associated with greater improvement in joint function and muscle strength of knee flexion and extension muscles in patients with knee cruciate ligament reconstruction. However, although the intervention was associated with a higher mean H/Q ratio, it did not increase the proportion of patients with a clinically normal H/Q ratio. Further prospective, multicenter studies are warranted to validate these findings.

Availability of Data and Materials

The data analyzed are available from the corresponding authors upon reasonable request.

Author Contributions

YL, WYD, and XYY contributed to the conception and design of the study and supervised the project. YL contributed to the writing of the manuscript. WJL, XRK, WYD and XYY contributed to the collection and organization of the data. TXC and HL contributed to the data analysis. WJL and XRK contributed to the review and proofreading of the report. All authors have been involved in revising the manuscript critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki. Ethical approval was obtained from the Ethics Committee of Affiliated Hangzhou First People's Hospital (Approval No.: 2026ZN222-1). As patient personal information was strictly confidential, and all data were anonymized and used solely for research analysis, informed consent was waived.

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Conflict of Interest

The authors declare no conflict of interest.

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